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CO_2 Emission Multiplier Effects of Taiwan's Electricity Sector by Input-output Analysis

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ABSTRACT

From 1990–2009, electricity has played a critical role in supporting industrial development and economic growth in Taiwan. In this study, a 42-sector input-output table provided the basis for examination of linkage effects among various sectors and electric industry concerning their CO_2 emissions. These forward and backward linkage effects were inferred from analysis of the sensibility index of dispersion and the power index of dispersion. From results we suggest that, according to the CO_2 multipliers and linkage effects, artificial fiber, coal products, cement, and land transportation are the top four CO_2-intensive sectors related to electricity sector in Taiwan. It is worth noting that many sectors in Taiwan have larger indirect CO_2 emissions than direct CO_2 emissions. This finding provides a focal point for researchers and related governmental agencies to explore mitigations for CO_2 reduction and to enhance effective environmental practices. Decision-makers from other countries with similar power plants may apply the similar approach and methodology to prioritize their strategies for abatement of CO_2 emissions from the electricity sector.

Keywords: Input-output analysis; Multiplier effect; CO_2 emission; Electricity sector; Inter-industry linkage.

INTRODUCTION

Simultaneous with the economic growth in Taiwan, electricity demand is rapidly increased to satisfy these needs. Taiwan now imports about 98% of large quantity raw fuels for power generation. The annual energy statistics from the Bureau of Energy (2010) showed that the gross power generation in Taiwan grew from 90,204 GWh in 1990 to 247,046 GWh in 2010, an average annual increase of 5.17% (Table 1). The state-run industry, Taiwan Power Company (TPC), generated 165,010 GWh, accounting for 66.8% of total output, followed by 40,787 GWh (16.5%) from independent power producers (IPPs) and 40,599 GWh (16.4%) from co-generation systems in 2010.

The electricity produced from thermal power plants increased rapidly from 49,147 GWh (54.5%) in 1990 to 197,113 GWh (79.8%) in 2010 (Table 1) (Bureau of Energy, 2011). On the other hand, due to the national goal of the "nuclear-free homeland" policy in Taiwan and the Fukushima nuclear accident in Japan, the government proposes that there is no extension for any existing nuclear power plants and wish to phase out most nuclear plants for a "nuclear-free homeland" in the future. The percentage of electricity produced from nuclear power plants decreased gradually from 36.4% in 1990 to 16.9% in 2010. In addition, the gross electricity generation of hydro-power systems reduced from 8,188 GWh (9.1%) in 1990 to 7,255 GWh (2.9%) in 2010. Wind power and other green energy supply systems only operated on a limited scale and comprised less than 0.5% in 2010. All of this indicates that thermal power generation is the dominant source of electricity in Taiwan.

Fuel consumption of TPC and independent thermal power plants in Taiwan for 1991–2010 is shown in Table 2. Considering TPC thermal power plants, the total fuel consumption increased from 13,172 thousand kilo liter of oil equivalent (KLOE) in 1991 to 28,860 thousand KLOE in 2010. Bituminous coal is the most important fuel supply, accounting for 54%, and the share of LNG, sub-bituminous coal, and fuel oil were about 29%, 9% and 7% in 2010. According to the National Energy Conservation and Carbon Reduction Master Program (2010) suggested that the quantity of GHG emissions in 2020 should be reduced to the level of that in 2005, and the quantity of GHG emissions in 2025 should be reduced to the level of that in 2000. Based on these goals, Taiwan Power Company has set up GHG control strategies to reduce GHG emissions

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(Taiwan Power Company, 2010). One of the strategies is to increase the ratio of natural gas power to 25% in 2025. Therefore, the fuel consumption of LNG has increased from 693 thousand KLOE in 1991 to 8,490 thousand KLOE in 2010, with an annual growth rate of 14.9%. The fuel consumption of diesel oil and fuel oil has decreased to 59 and 2,113 thousand KLOE in 2010 with an attempt to reduce carbon emission and lower electricity generation costs.

Table 1. Electricity generation in Taiwan (1990–2010) (Unit: GWh).

Year	Thermal power		Hydro power		Nuclear power		Geothermal electricity, Solar photovoltaic & wind energy		Total
1990	49,147	54.5%	8,188	9.1%	32,866	36.4%	3	0.00%	90,204
1991	58,378	58.9%	5,508	5.6%	35,290	35.6%	2	0.00%	99,178
1992	63,332	60.0%	8,351	7.9%	33,845	32.1%	2	0.00%	105,530
1993	74,132	64.3%	6,719	5.8%	34,354	29.8%	1	0.00%	115,206
1994	80,878	64.9%	8,887	7.1%	34,871	28.0%	0	0.00%	124,635
1995	88,922	66.8%	8,879	6.7%	35,316	26.5%	0	0.00%	133,117
1996	95,131	67.0%	9,044	6.4%	37,788	26.6%	0	0.00%	141,962
1997	104,650	69.5%	9,567	6.4%	36,269	24.1%	0	0.00%	150,486
1998	115,754	70.9%	10,608	6.5%	36,824	22.6%	0	0.00%	163,186
1999	122,115	72.1%	8,942	5.3%	38,416	22.7%	0	0.00%	169,473
2000	137,480	74.4%	8,870	4.8%	38,503	20.8%	2	0.00%	184,854
2001	143,863	76.3%	9,169	4.9%	35,486	18.8%	12	0.01%	188,532
2002	152,900	76.9%	6,360	3.2%	39,553	19.9%	16	0.01%	198,829
2003	163,262	78.1%	6,895	3.3%	38,890	18.6%	24	0.01%	209,070
2004	172,325	78.9%	6,556	3.0%	39,490	18.1%	26	0.01%	218,397
2005	179,475	78.9%	7,910	3.5%	39,972	17.6%	92	0.04%	227,449
2006	187,316	79.6%	7,999	3.4%	39,870	16.9%	279	0.12%	235,465
2007	193,780	79.7%	8,350	3.4%	40,539	16.7%	446	0.18%	243,115
2008	189,133	79.4%	7,772	3.3%	40,827	17.1%	593	0.25%	238,326
2009	180,275	78.5%	7,053	3.1%	41,571	18.1%	795	0.35%	229,694
2010	197,113	79.8%	7,255	2.9%	41,629	16.9%	1,048	0.42%	247,046

Data source: Energy statistical annual reports, 2011.

Table 2. Fuel mix of TPC and independent thermal power plants in Taiwan (1991–2010) (Unit: 10^3 K.L.O.E.).

Year	Bituminous coal–Steam coal		Sub-bituminous coal		Diesel oil		Fuel oil		LNG		Total	
	TPC*	Indep.**	TPC	Indep.	TPC	Indep.	TPC	Indep.	TPC	Indep.	TPC	Indep.
1991	6,343	0	0	0	489	0	5,647	0	693	0	13,172	0
1992	8,040	0	0	0	268	0	4,697	0	716	0	13,721	0
1993	8,932	0	0	0	394	0	5,456	0	595	0	15,377	0
1994	9,657	0	0	0	664	0	5,276	0	1,268	0	16,866	0
1995	9,788	0	35	0	762	0	6,429	0	1,358	0	18,372	0
1996	11,616	0	152	0	505	0	5,526	0	1,459	0	19,257	0
1997	13,000	0	263	0	158	0	6,032	0	2,071	0	21,525	0
1998	13,470	0	1,364	0	371	0	5,884	0	3,144	0	24,234	0
1999	13,554	855	1,512	0	583	3	6,042	6	3,104	20	24,795	885
2000	12,429	2,237	2,959	0	509	3	5,854	7	3,469	94	25,220	2,341
2001	11,999	3,262	3,662	0	143	3	4,990	6	4,066	233	24,860	3,503
2002	12,793	4,403	3,294	0	133	18	3,839	7	4,271	924	24,330	5,352
2003	13,503	5,547	3,188	0	111	13	3,418	5	4,401	1,023	24,621	6,588
2004	13,848	5,309	3,262	0	81	8	2,860	5	4,186	2,580	24,237	7,902
2005	15,612	5,559	2,879	0	140	9	2,647	6	4,627	2,787	25,905	8,362
2006	16,221	5,700	3,186	0	255	6	3,389	4	5,033	2,617	28,084	8,327
2007	16,096	5,775	3,677	0	120	9	2,982	3	5,798	2,702	28,673	8,489
2008	15,981	5,638	3,524	0	128	7	2,799	4	6,505	2,882	28,937	8,531
2009	14,266	6,145	3,765	0	59	4	1,552	1	6,092	2,780	25,734	8,931
2010	15,555	6,186	2,643	0	59	4	2,113	3	8,490	3,023	28,860	9,215

Data source: Bureau of Energy, 2011.

* TPC = Taiwan Power Company thermal power plants, ** Indep. = Independent thermal power plants.

Also, independent thermal power plants (Table 2) have played an important role in the energy structure. The total fuel consumption increased from 885 thousand KLOE in 1999 to 9,215 thousand KLOE in 2010 from these plants. The first independent power plant, located in Yunlin County, started operation in 1999, and then the proportion of IPPs power generation in Taiwan increased gradually. The bituminous coal and LNG were the major fuel sources, accounting for 67% and 33%, respectively in 2010. Consider the quantity of GDP, electricity consumption and energy consumption in Taiwan during 1995 to 2010 (Table 3), whereas GDP increased from 7,536 × 10^9 NT$ in 1995 to 14,210 × 10^9 NT$ in 2010, with an annual growth rate of 4.32%.

It is worth noting that the electricity consumption in Taiwan increased from 30,432 × 10^3 KLOE in 1995 to 58,466 × 10^3 KLOE in 2010, with an annual growth rate of 4.45%. Moreover, the annual growth rate of energy consumption for this 15-year period was 3.83%. The electricity consumption growth rate was higher than the energy consumption growth rate; this shows that the electricity consumption was more significant than the consumption of other energy sources such as coal and oil in Taiwan. In other words, electricity played a very critical role in support of industrial development and economic growth.

Numerous important studies related to characteristics of air pollutants and air quality improvement had been extensively discussed in recent years. Hung *et al.* (2005) and Hsieh and Chen (2010) evaluated the characteristics of volatile organic compounds (VOC) and ammonia around industrial parks. Lee *et al.* (2003; 2004) and Hu *et al.* (2009) evaluated the characteristics of polychlorinated dibenzo-*p*-dioxins/dibenzofuran in Taiwan. Wang *et al.* (2010) evaluated the characteristics of heavy metals emitted from power plants. Fang *et al.* (2011) measured the concentration of As and dry deposition fluxes. Also, issues related to climate change and greenhouse gas (GHG) effects have gained significant notice during the two decades. In this study, our purpose focused on the modeling of economic-based linkage effects of CO_2 emissions from electricity sector in Taiwan. The linkage effect analysis is used to evaluate the inter-industry relationships of the electricity sector for a 42-sector input-output table. The sensibility index of dispersion and the power index of dispersion are calculated to measure the forward and backward linkage effects. In addition, the CO_2 multipliers of all 42 sectors from fossil fuel combustion in Taiwan in 2004 and 2006 are calculated to identify the sum of direct and indirect CO_2 emissions intensity. For the electricity sector, we further discuss the differences between the quantity of CO_2 emissions factor and that of CO_2 multipliers.

INPUT-OUTPUT ANALYSIS

Literature Review

A number of studies have applied input-output analysis to environmental issues related to the energy sector. The pioneer in this area was Leontief (1970), who initiated input-output analysis for computing pollutant emission and evaluating control strategies for major industries in the U.S.A. Chen and Wu (1994) applied input-output analysis to analyze the sources of change in the electricity demands of the industrial sectors in Taiwan. Their results showed that economic growth had the dominant impact on electricity use. Furthermore, Lin and Chang (1997) used input-output analysis to assess the impacts of oil consumption industries on environmental quality and inter-industry relationships

Table 3. GDP, electricity consumption and energy consumption in Taiwan (1990–2010).

	GDP	Economic growth rate	Electricity consumption	Electricity consumption growth rate	Energy consumption	Energy consumption growth rate
	10^9 NT$		10^3 KLOE		10^3 KLOE	
1995	7,536		30,432		68,473	
1996	7,954	5.54%	32,288	6.10%	71,755	4.79%
1997	8,389	5.48%	35,100	8.71%	75,357	5.02%
1998	8,680	3.47%	38,566	9.88%	80,291	6.55%
1999	9,198	5.97%	41,405	7.36%	84,652	5.43%
2000	9,731	5.80%	46,210	11.60%	91,737	8.37%
2001	9,571	–1.65%	47,290	2.34%	97,055	5.80%
2002	10,074	5.26%	48,897	3.40%	100,498	3.55%
2003	10,444	3.67%	50,996	4.29%	104,370	3.85%
2004	11,090	6.19%	53,088	4.10%	108,760	4.21%
2005	11,612	4.70%	55,455	4.46%	111,168	2.21%
2006	12,243	5.44%	57,662	3.98%	113,739	2.31%
2007	12,976	5.98%	59,157	2.59%	119,188	4.79%
2008	13,071	0.73%	58,620	–0.91%	115,699	–2.93%
2009	12,834	–1.81%	55,729	–4.93%	113,073	–3.22%
2010	14,210	10.72%	58,466	4.91%	120,308	3.98%
1995–2010		4.32%		4.45%		3.83%

Data source: Directorate-General of Budget, Accounting and Statistics, 2011; Bureau of Energy, 2011.

in Taiwan. Results of inter-industry linkages confirm that investment of the power generation, other industrial chemicals, paper products, non-metallic mineral products, petrochemical materials, rubber products, cement and textiles should be adjusted to better energy efficiency, environmental quality and economic bases.

Han *et al.* (2004) used input-output analysis to investigate the role of the four electric power sectors (hydroelectric, fossil-fuels, nuclear and non-utility) in the Korean national economy for the period 1985–1998. The results revealed that the non-utility electric sector was superior in terms of national economy-wide effects to the other three sectors through out the period. Yabe (2004) examined the factors that have an effect on CO_2 emissions from Japanese industries between 1985 and 1995 by using input–output tables. The backward and forward linkage effects of each sector were calculated to show the extent of each sector spreads or receives CO_2 emissions across all of sectors. The results showed that the backward and forward linkage effects decreased during the late in 1980s but not the recession of the early 1990s, while the chemical products and electrical machinery sectors continued to reduce both effects. This indicates that both sectors were relatively successful in decreasing their CO_2 emissions between 1985 and 1995. Kwak *et al.* (2005) employed input-output analysis to examine the role of the maritime industry in the Korean economy for the period 1975–1998. They addressed inter-industry linkage effects in 32 sectors, production-inducing effects, employment-inducing effects and supply-shortage effects of the maritime sector.

Yoo and Yoo (2009) applied input-output analysis to investigate the role of the nuclear power generation in the Korean economy. They paid particular attention to the nuclear power generation sector by taking the sector as exogenous and then investigating its economic impacts. Alcántara *et al.* (2010) identify those sectors that contribute most to electricity consumption in Spain, using a methodology based on input–output tables, and to derive some recommendations aimed at increasing energy efficiency in those sectors. The results suggested that policy instruments should be applied in order to increase both energy efficiency in the electricity generation sector as well as electricity efficiency in end-use electricity sectors.

All of the above studies indicate that the IO method is a very powerful tool to analyze the interrelationships and linkages of energy uses and effects on CO_2 emissions. In order to better understand this method, it is important to mention the basic theory related to it.

General Framework of Input-output Analysis

Input–output analysis is a top-down method to analyze mutual inter-relationships between various sectors of a complex economic system. Each sector's production process can be represented by a vector of structural coefficients that describes quantitatively the relationship between the input into and the output of production. Wassily W. Leontief (Leontief, 1970) who received the Nobel Prize in 1973 constructed the basic framework of input-output study, he also indicated that the interdependence between the sectors of a given economy system can be defined by a set of linear equations to express the balances between the total input and the aggregated output of each product and service.

The basic equations of the input–output model can be presented as: (Lin and Chang, 1997)

$$\sum_{j=1}^{n} x_{ij} + F_i = X_i \tag{1}$$

$$\sum_{i=1}^{n} x_{ij} + V_j = X_j \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j + F_i = X_i \tag{3}$$

where

X_i = total gross output produced in sector *i*,
X_j = total gross input required in sector *j*,
F_i = product of sector i delivered to the final demand,
V_j = final payment (value added) by sector *j*,
x_{ij} = the amount of the product sector *i* used by per unit of output of sector *j*,
$a_{ij} = x_{ij}/X_j$, the direct input or technical coefficient of product of sector *i* into sector *j*.

Thus, the technical structure of the entire system can be represented by the matrix of technical input–output coefficients of all its sectors. Eq. (3) can be rewritten in the following matrix form:

$$\begin{aligned} &AX + F = X \\ &(I - A)\,X = F \\ &\text{or} \\ &X = (I - A)^{-1} F \\ &\quad = [b_{ij}]\,F \\ &\quad = B\,F \end{aligned} \tag{4}$$

where

A = the direct input cofficient matrix of a_{ij},
I = the identity matrix,
B = the Leontief inverse matrix,
b_{ij} = the element of the Leontief inverse matrix, representing the total direct and indirect requirement of sector *i* by per unit of output sector *j* to final demand.

Linkage Effect Analysis

Besides input-output analysis, linkages between inputs and outputs are equally important. The concept of linkage effect was developed by Hirschman (1985). It is based on the assumption that the economy could be promoted by adopting an imbalanced investment policy to generate an equilibrium growth among the related industries. In other words, economy in related industries can be boosted through linking input/output activities.

In general, linkage effect is classified into "forward linkage effect" and "backward linkage effect". The former indicates that the increase of a certain industry's outputs which can used as materials to other industries may promote the outputs of other industries, with the latter indicating that production of a certain industry may induce the consumption of more products from other industries as the inputs to the certain industry (Lin and Chang, 1997). The calculation of the inter-industry linkage effect can be presented as the following (Directorate-General of Budget, Accounting and Statistics, 2004):

$$U_i^f = \frac{\sum_{j=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n} b_{ij} \sum_{j=1}^{n} b_{ij}} \quad (5)$$

$$U_j^b = \frac{\sum_{i=1}^{n} b_{ij}}{\frac{1}{n}\sum_{i=1}^{n} b_{ij} \sum_{j=1}^{n} b_{ij}} \quad (6)$$

where, U_i^f is the sensibility index of dispersion, denoting the forward linkage effect,

U_j^b is the power index of dispersion, denoting the backward linkage effect,

b_{ij} is the element of the Leontief inverse matrix,

$\sum_{j=1}^{n} b_{ij}$ is the sum of elements in row i of the Leontief inverse matrix,

$\sum_{i=1}^{n} b_{ij}$ is the sum of elements in column j of the Leontief inverse matrix.

CO_2 Multipliers

By regarding pollution as the “externality” of regular economic activities, many forms of pollutants can be related in a measurable way to energy consumption or production processes (Lin and Chang, 1997). In this study, the category “externalities” is incorporated into the conventional input-output analysis. The concept of multiplier was first applied by Wright (1974) for defining the energy commodity in input-output analysis. Also, Miller and Blair (1985) elaborated the energy and environmental input-output analysis to quantify the total impact of energy commodity input coefficients and pollutant output coefficients. In this study, the CO_2 multipliers were calculated by the following Eq. (7):

$$Q = q\,(I - A)^{-1} \quad (7)$$

where

$Q = [q_j]_{1\times n}$, total impact of CO_2 emission coefficient, which specifies the amount of CO_2 emitted directly and indirectly caused by per $\$10^6$ worth of output of industry j,

$(I - A)^{-1}$ = the Leontif inverse matrix,

$q = [q_j]_{1\times n}$, CO_2 emission coefficient from industry j (ton pollutant/$\$10^6$).

DATA CONSOLIDATION

The basic input-output table was originally developed by the Directorate-General of Budget, Accounting and Statistics of Executive Yuan in Taiwan. The input-output table used in this study includes a 160-sector table for 2001 (Directorate-General of Budget, Accounting and Statistics, 2004), a 161-sector table for 2004 (Directorate-General of Budget, Accounting and Statistics, 2007), and a 166-sector table for 2006 (Directorate-General of Budget, Accounting and Statistics, 2009) which is the most update information in Taiwan regarding IO table.

The energy consumption of the electricity sector is based on the data from the ‘‘Taiwan Energy Balance Sheets’’ (Bureau of Energy, 2010). Because the sector classifications of the basic input-output table and the ‘‘Taiwan Energy Balance Sheets’’ are not identical, we combined them into a 42-sector table (Table 4). In addition, the CO_2 emissions from fuel combustion of 42 sectors are estimated according to the IPCC guidelines (IPCC, 2006), while emissions caused by the electricity and power generation sectors are allocated to various industries according to the rate of electricity consumption.

RESULTS AND DISCUSSION

Inter-industry Relationships

The results of inter-industry relationships (Table 5) show that the electricity sector has increased forward linkage effects (sensibility index of dispersion > 1) in 2004 and 2006. Thus, the electricity sector is indispensable in supporting other industries as intermediate inputs or services to their production development. Moreover, the ranking of the electricity sector’s forward linkage effect did not change much from 2004 to 2006. This reveals that the electricity sector has always been one of the most important sectors to support the economic development and industrial growth in Taiwan.

On the contrary, the electricity sector has relatively small backward linkage effects (power index of dispersion < 1) for 2004 and 2006; therefore, the development of the electricity sector would not greatly promote the progress of its upstream sectors listed in the input-output table. However, the electricity sector’s backward linkage effects increased from 0.806 in 2004 to 0.934 in 2006, and its ranking improved by three places. It shows that the electricity sector has gradually increased in importance for advancing the development of other raw-material-related upstream industries. The overall linkage effects and rankings of the electricity sector are 2.107 (14) and 2.138 (12) in 2004 and 2006. This means that the electricity sector plays one of the most critical roles among the entire industries in Taiwan, and it can significantly influence other industry’s development.

The top ten sectors with high forward/backward linkage effects to the electricity sector in 2004 and 2006 are presented in Table 6 and Table 7. The results show that all sectors such as “crude petroleum, coal & natural gas extraction” in Table 6 are major suppliers that support the power generation process in the electricity sector (by definition of forward linkage). When more electricity is produced, it increases the demand of intermediate inputs such as coal and natural gas. The upstream sectors like the

Table 4. Sector classification.

	Sector	Energy balance sheets	161-sector IO table (2004)	161-sector IO table (2006)
1	Agricultural & forestry	80	1–9, 11	1–8, 10
2	Fishery products	81	12	11
3	Crude petroleum, coal & natural gas extraction	20, 23	13	12, 1520
4	Minerals	33	14, 15, 16	13, 14, 15[a]
5	Food, tobacco & alcoholic beverages	34	17–32	16–30
6	Fabrics & wearing apparel	35	33–41	31–39
7	Leather and products	36	42–44	40–42
8	Wood, bamboo & rattan products	37	45–48	43–45, 103
9	Paper and products	38	49–50	46, 47
10	Printing	39	51–52	48, 131
11	Petrochemical raw materials	43, 44	54	52
12	Basic chemical materials	42	53, 59	51, 55
13	Chemical products	45, 48, 49	55, 60–64	53, 58–62
14	Artificial fibers	46	56, 57	56, 57
15	Plastics (synthetic resins)	47	58	54
16	Petroleum refining products	24	65	49
17	Coal products	21	66	50
18	Rubber products	50	67	63
19	Plastics products	51	68–69	64
20	Other non-metallic mineral products	54, 55, 56	70–71, 74	65, 66, 69
21	Cement	53	72–73	67, 68
22	Iron & steel	22, 58	75–76	70, 71
23	Non-ferrous metal	59, 60	77–81	72, 73, 74, 104
24	Metal products	61	82–85	75–78
25	Machinery	62	86–90	94–97, 107
26	3C products manufacturing	63, 64	91–104	79–87, 89–93
27	Transport equipments	65	105–109	98–102
28	Other manufactures	66, 67, 70	110–112	88, 105, 106
29	Electricity generation	25, 26, 27	113	108
30	Gas supply	28	114	109
31	Water supply	68	115	110
32	Construction	69	116–119	115–118
33	Wholesale & retail trade	83	120–123	119–121
34	Land Transportation	74	127	123
35	Other Transportation	72–73, 75–78	126, 128–129	122, 124, 125
36	Supporting services to transportation	85	130	126
37	Warehousing & storage	86	132	127
38	Postal & telecommunication services	87	133–134	128, 134
39	Finance & Insurance	88	135–137	137–139
40	Accommodation & food services	84	124–125	129–130
41	Public administration services	91	160	155
42	Other services	89, 90, 92	10, 131, 138–159, 161	9, 111–114, 132–133, 135–136, 140–154, 155–156

Note: [a] In 2006, 15 represents the "other non-metal mineral" sector without 1520 (coal).

Table 5. Inter-industry relationships of the electricity sector in Taiwan.

Year	Sensibility index of dispersion	Ranking*	Power index of dispersion	Ranking*	Overall linkage	Ranking*
2004	1.301	9	0.806	30	2.107	14
2006	1.204	8	0.934	27	2.138	12

* Ranking is the order of "electricity sector" among the total 42 sectors.

Table 6. Top 10 large forward linkage effects sectors to the electricity sector.

Ranking	2004	2006
1	Crude petroleum, coal & natural gas extraction	Crude petroleum, coal & natural gas extraction
2	Petroleum refining products	Petroleum refining products
3	Other services	Other services
4	3C products manufacturing	Machinery
5	Finance & Insurance	Wholesale & retail trade
6	Iron & steel	Iron & steel
7	Machinery	Finance & Insurance
8	Wholesale & retail trade	3C products manufacturing
9	Basic chemical materials	Chemical products
10	Construction	Non-ferrous metal

Table 7. Top ten large backward linkage effects sectors to the electricity sector.

Ranking	2004	2006
1	Basic chemical materials	Artificial fibers
2	Artificial fibers	Basic chemical materials
3	Plastics (synthetic resins)	Plastics (synthetic resins)
4	Petrochemical raw materials	Petrochemical raw materials
5	Fabrics & wearing apparel	Fabrics & wearing apparel
6	Paper and products	Paper and products
7	Plastic products	Plastic products
8	Non-ferrous metal	Other non-metallic mineral products
9	Other non-metallic mineral products	Cement
10	Cement	Iron & steel

"petroleum refining products" sector must increase their outputs to meet the raising demand from electricity generation, and then the development of these upstream sectors would be promoted (by definition of backward linkage). In addition, all sectors such as "artificial fibers" in Table 7 are high energy intensive sectors. In other words, these sectors are main electricity consumers in Taiwan. The production processes of these sectors always depend on a large, reliable, and steady electricity supply. The electricity sector supports the development of these sectors.

CO_2 Emissions Factors and Multipliers

The CO_2 emissions, monetary CO_2 emissions factors and CO_2 multipliers from fossil fuel combustion in Taiwan in 2004 and 2006 are given in Tables 8 and 9. As mentioned above, CO_2 emissions that resulted from electricity generation are allocated to various sectors according to the percentage of each sector's electricity consumption. Therefore, the quantity of CO_2 emissions of each sector in Tables 8 and 9 results from fossil fuel consumption and purchased electricity. Results reveal that the "land transportation", "iron and steel" and "petrochemical raw materials" sectors are the most significant CO_2 emissions sources for the two years. These sectors are highly energy-intensive, and the sum of their CO_2 emissions represents more than 30% of the total CO_2 emissions.

However, after we examine CO_2 emissions per million USD gross output (the monetary CO_2 emissions factors), the highly direct CO_2-intensive sectors are "land transportation", "coal products", and "cement". In spite of the fact that CO_2 emissions of the "coal products", and "cement" sectors are not huge (see Tables 8 and 9), it is nevertheless significant because the gross output of two sectors are very small, making them significant CO_2 emissions sources in Taiwan.

After we multiply the monetary CO_2 emissions factors with the Leontief inverse matrix, the CO_2 multipliers show that, considering the linkage effects, the "artificial fibers", "coal products", "cement" and "land transportation" are major CO_2-intensive sectors among all 42 sectors in Taiwan. It is worth noting that for the "artificial fibers" sector the quantity of its CO_2 multiplier is almost double the quantity of its monetary CO_2 emissions factor. This reveals that the level of indirect CO_2 emissions from other sectors is equivalent to that of direct CO_2 emissions from the "artificial fibers" sector itself. In fact, many sectors in Taiwan have larger indirect CO_2 emissions than direct CO_2 emissions (see Table 10). The proportions of indirect emissions from other sectors are increasing gradually to the point where there would be a huge underestimation of global warming effects if the related sectors in the input-output table are omitted from the calculations.

Table 11 shows the CO_2 emissions, monetary CO_2 emissions factor, CO_2 multiplier and ranking of the electricity sector. The results show that although the CO_2 emissions increase continuously from 2004 to 2006, the monetary CO_2 emissions factor decreases from 720.22 ton CO_2/million USD in 2004 to 705.50 ton CO_2/million USD in 2006. Since that the gross output of electricity sector increases significantly from 13,163 million USD in 2004 to 15,700 million USD in 2006. Considering the linkage effects, the CO_2 multiplier is clearly unchanged between 2004 and 2006; therefore, the interrelationship of the electricity sector to related sectors is stable (see Table 5).

Because the electricity sector is one of the fundamental industries in Taiwan, it uses a lot of fossil fuel inputs in support of electricity generation. For this reason, the CO_2 multiplier is slightly larger than the monetary CO_2 emissions factor of the electricity sector. The intensity of direct CO_2 emissions from electricity generation is higher than that of indirect CO_2 emissions from related sectors in the input-output table.

CONCLUSIONS

In this study, the forward and backward linkage effects of the electricity sector are estimated. Results show that the electricity sector plays a critical role for the entire economy in Taiwan because it can significantly influence other industry's development. The electricity sector is indispensable in support of production development of high energy-intensive sectors such as the "artificial fibers", "paper and products" and "cement" sectors in the input-output table.

In addition, we identify the sum of direct and indirect CO_2 emissions intensity by calculating the CO_2 multipliers of all 42 sectors from fossil fuel combustion in Taiwan in

Table 8. CO_2 emissions, monetary emissions factor and multiplier in 2004.

Sector	Gross Output (million USD)	CO_2 emissions (ton CO_2)	Monetary CO_2 emission factor (ton CO_2/million USD)	CO_2 multiplier (ton CO_2/million USD)
1 Agricultural & forestry	12,654	829,496	65.55	374.99
2 Fishery products	2,259	3,726,656	1,143.62	1,564.03
3 Crudepetroleum, coal & natural gas extraction	18,849	57,271	3.04	135.72
4 Minerals	4,542	325,582	71.68	453.17
5 Food, tobacco & alcoholic beverages	22,298	3,295,408	147.79	594.60
6 Fabrics & wearing apparel	18,927	8,694,796	459.39	2,069.82
7 Leather and products	1,914	297,671	155.55	813.94
8 Wood, bamboo & rattan products	3,103	287,630	92.70	640.97
9 Paper and products	7,683	5,024,999	654.00	1,528.34
10 Printing	5,927	308,360	7.00	626.87
11 Petrochemical raw materials	26,573	29,137,337	52.02	2,597.52
12 Basic chemical materials	9,094	3,222,031	1,096.50	1,318.74
13 Chemical products	13,675	3,659,053	354.31	1,221.16
14 Artificial fibers	5,223	10,391,695	267.56	3,936.03
15 Plastics (synthetic resins)	16,301	4,909,219	1,989.79	2,315.42
16 Petroleum refining products	25,971	10,604,354	301.16	631.96
17 Coal products	1,163	3,274,966	408.32	3,363.83
18 Rubber products	2,714	828,771	2,816.43	1,080.53
19 Plastics products	15,513	4,497,785	305.35	1051.85
20 Other non-metallic mineral products	6,787	3,653,957	289.38	1,067.67
21 Cement	3,164	7,657,994	2,420.23	3,460.56
22 Iron & steel	43,430	26,063,133	600.12	1,903.11
23 Non-ferrous metal	16,061	1,073,661	66.85	934.34
24 Metal products	13,841	3,672,428	265.34	1,209.64
25 Machinery	38,160	968,380	25.38	876.15
26 3C products manufacturing	154,234	14,570,090	94.47	705.59
27 Transport equipments	25,767	1,498,037	58.14	746.80
28 Other manufactures	18,324	1,226,561	66.94	800.69
29 Electricity generation	13,163	9,480,550	720.22	1,001.86
30 Gas supply	1,115	333,922	299.37	695.47
31 Water supply	1,041	712,655	684.85	1,055.06
32 Construction	32,433	588,902	18.16	1,052.03
33 Wholesale & retail trade	72,978	1,259,619	17.26	173.15
34 Land Transportation	9,479	34,541,919	3,644.08	3,904.98
35 Other Transportation	16,644	8,389,257	504.04	1,016.73
36 Supporting services to transportation	3,593	6,301,922	1,753.73	2,027.21
37 Warehousing & storage	692	404,361	584.28	974.30
38 Postal & telecommunication services	13,019	807,910	62.06	187.82
39 Finance & Insurance	46,409	643,821	13.87	107.11
40 Accommodation & food services	12,960	2,169,494	167.40	376.74
41 Public administration services	30,611	5,021,272	164.04	270.08
42 Other services	139,070	15,115,375	108.69	286.93

Table 9. CO_2 emissions, monetary emissions factor and multiplier in 2006.

Sector	Gross Output (million USD)	CO_2 emissions (ton CO_2)	Monetary CO_2 emission factor (ton CO_2/million USD)	CO_2 multiplier (ton CO_2/million USD)
1 Agricultural & forestry	13,221	949,782	71.84	368.15
2 Fishery products	2,998	2,345,582	782.37	1,192.95
3 Crude petroleum, coal & natural gas extraction	32,418	53,210	1.64	250.19
4 Minerals	4,313	337,842	78.33	621.36
5 Food, tobacco & alcoholic beverages	22,941	3,268,198	142.46	555.92
6 Fabrics & wearing apparel	17,956	743,064	413.82	1,931.03
7 Leather and products	2,535	265,270	104.65	884.84
8 Wood, bamboo & rattan products	3,382	301,507	89.14	602.78
9 Paper and products	7,872	4,933,414	626.73	1,511.86
10 Printing	6,285	338,600	53.88	628.16
11 Petrochemical raw materials	34,734	31,176,925	897.58	2,343.29
12 Basic chemical materials	10,448	3,877,313	371.11	1,266.89
13 Chemical products	16,772	3,614,123	215.48	1,201.72
14 Artificial fibers	5,015	9,753,385	1,944.65	3,807.89
15 Plastics (synthetic resins)	19,165	5,618,424	293.16	2,235.16
16 Petroleum refining products	40,119	11,138,746	277.64	569.77
17 Coal products	1,268	3,417,692	2,695.46	3,309.46
18 Rubber products	3,351	834,949	249.16	1,007.83
19 Plastics products	14,449	4,644,542	321.43	1668.3
20 Other non-metallic mineral products	5,142	3,755,671	730.38	1,383.27
21 Cement	4,412	10,088,000	2,286.33	3,334.46
22 Iron & steel	15,841	27,266,762	594.82	1,908.34
23 Non-ferrous metal	29,133	1,004,039	34.46	729.28
24 Metal products	16,677	3,917,363	234.90	1,124.51
25 Machinery	47,561	1,086,715	22.85	753.47
26 3C products manufacturing	192,026	18,454,112	96.10	665.42
27 Transport equipments	24,473	1,683,483	68.79	676.23
28 Other manufactures	18,139	1,527,437	84.21	775.97
29 Electricity generation	15,700	11,076,173	705.50	1,062.89
30 Gas supply	1,277	427,152	334.53	711.65
31 Water supply	1,162	770,990	663.75	1,086.38
32 Construction	38,692	580,486	15.00	959.40
33 Wholesale & retail trade	110,563	1,435,174	12.95	155.77
34 Land Transportation	9,538	35,492,225	3,720.99	3,951.13
35 Other Transportation	15,834	8,832,030	557.78	1,115.73
36 Supporting services to transportation	8,096	6,276,914	775.34	971.68
37 Warehousing & storage	772	463,231	600.36	1,038.99
38 Postal & telecommunication services	13,076	899,857	68.82	261.08
39 Finance & Insurance	39,100	717,332	18.35	97.18
40 Accommodation & food services	20,872	2,536,005	121.51	410.40
41 Public administration services	37,122	5,367,016	144.58	269.80
42 Other services	156,988	17,125,268	109.09	285.77

2004 and 2006. We find that the "land transportation", "iron and steel" and "petrochemical raw materials" sectors are the most significant CO_2 emissions sources. Moreover, from the viewpoint of the monetary CO_2 emissions factor, the highly direct CO_2-intensive sectors are "land transportation", "coal products", and "cement" sectors. After considering the linkage effects of sectors, along with the above three highly direct CO_2-intensive sectors, the "artificial fibers" sector is also a high CO_2-intensive sector among all 42 sectors in Taiwan because of its huge indirect CO_2 emission intensity. There would be an underestimation of global warming effects if the indirect CO_2 emissions from the related sectors in the input-output table are omitted from the calculations. However, for the electricity sector, the indirect CO_2 emission intensity is not obvious because the electricity industry uses many primary energy inputs to produce electricity. Suggestions for mitigating indirect CO_2 emissions are as follows. (1) Higher standards and effective incentives need to be enhanced in order to promote more energy-savings in industry. The government must require high energy intensity industries such as IC, petroleum, steel, etc. to meet stricter standards and to upgrade their energy

Table 10. Direct/Indirect effects of CO_2 emissions for 42 sectors in Taiwan.

Sector		2004		2006	
		Direct effect	Indirect effect	Direct effect	Indirect effect
1	Agricultural & forestry	17%	83%	20%	80%
2	Fishery products	73%	27%	66%	34%
3	Crude petroleum, coal & natural gas extraction	2%	98%	1%	99%
4	Minerals	16%	84%	13%	87%
5	Food, tobacco & alcoholic beverages	25%	75%	26%	74%
6	Fabrics & wearing apparel	22%	75%	21%	79%
7	Leather and products	19%	81%	12%	88%
8	Wood, bamboo & rattan products	14%	86%	15%	85%
9	Paper and products	43%	57%	41%	59%
10	Printing	8%	92%	9%	91%
11	Petrochemical raw materials	42%	58%	38%	62%
12	Basic chemical materials	29%	73%	29%	71%
13	Chemical products	22%	78%	18%	82%
14	Artificial fibers	51%	49%	51%	49%
15	Plastics (synthetic resins)	13%	87%	13%	87%
16	Petroleum refining products	65%	35%	49%	51%
17	Coal products	84%	16%	81%	19%
18	Rubber products	28%	72%	25%	75%
19	Plastics products	19%	81%	19%	81%
20	Other non-metallic mineral products	50%	50%	53%	47%
21	Cement	70%	30%	69%	31%
22	Iron & steel	32%	68%	31%	69%
23	Non-ferrous metal	7%	93%	5%	95%
24	Metal products	22%	78%	21%	79%
25	Machinery	3%	97%	3%	97%
26	3C products manufacturing	13%	87%	14%	86%
27	Transport equipments	8%	92%	10%	90%
28	Other manufactures	8%	92%	11%	89%
29	Electricity generation	72%	28%	66%	34%
30	Gas supply	43%	57%	47%	53%
31	Water supply	65%	35%	61%	39%
32	Construction	2%	98%	2%	95%
33	Wholesale & retail trade	10%	90%	8%	92%
34	Land Transportation	93%	7%	94%	6%
35	Other Transportation	50%	50%	50%	50%
36	Supporting services to transportation	87%	13%	80%	20%
37	Warehousing & storage	60%	40%	58%	42%
38	Postal & telecommunication services	33%	67%	26%	74%
39	Finance & Insurance	13%	87%	19%	81%
40	Accommodation & food services	44%	56%	30%	70%
41	Public administration services	61%	39%	54%	46%
42	Other services	37%	63%	38%	62%

Table 11. CO_2 emissions, monetary emissions factor, multiplier and ranking of the electricity sector.

Year	CO_2 emissions ($t\ CO_2$)	Ranking*	Monetary CO_2 emissions factor ($t\ CO_2$/million USD)	Ranking*	CO_2 multiplier ($t\ CO_2$/million USD)	Ranking*
2004	9,480,550	8	720.22	8	1,001.86	21
2006	11,076,173	7	705.50	9	1,062.89	18

* Ranking is the order of "electricity sector" among the total 42 sectors

efficiencies; these industries must also develop voluntary initiatives for energy savings and CO_2 reduction. (2) Major industries in downstream of electricity sector should adjust the fuel consumption structure to low-carbon emissions, and lower the energy intensity by increasing the proportion of green energy. The industries should accelerate the replacement of antiquated facilities, and moves toward green manufacturing. (3) Demand-side management should be strengthened by all energy-related sectors so as to cut consumer demand and thereby save more energy. Furthermore, the transportation, residential and commercial sectors must promote the following programs: efficient public transportation, green buildings and energy-saving facilities, upgrade of basic equipment and infrastructure.

In fact, many sectors in Taiwan have larger indirect CO_2 emissions than direct CO_2 emissions. As such, our findings are important to decision-makers to explore effective mitigations on CO_2 reduction from the electric power industry and relevant industries of Taiwan, and also this study is equally important to researchers from other countries and related agencies that have similar power plants to develop a strategic methodology and effective measures for coping with increased CO_2 emissions from their electricity-generating power plants.

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